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Detection of In-Plane Displacements of Acoustic Wave Fields Using Extrinsic Fizeau Fiber Interferometric Sensors

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ABSTRACT: In this paper we report quantitative measurements of the in-plane particle displacement components of ultrasonic surface acoustic wave fields using extrinsic Fizeau fiber interferometric (EFFI) sensors. Wave propagation in materials and the way in which particle displacement fields interact with the fiber sensor elements are briefly discussed. Calibrated experimental results obtained for simulated acoustic emission events on homogeneous metal test specimens are reported and compared to previous results obtained using piezoelectric transducers.

1. INTRODUCTION

Optical fiber sensors have been developed during the past fifteen years for measurements of strain, temperature, pressure and other physical observables. Such sensors have the general advantages of high sensitivity, wide dynamic range, capability for extreme high and low temperature operation, and avoidance of electromagnetic interference and instrumentation ground loops. Fiber sensors may be categorized by the propagating optical field observable which is modulated by the external environmental property. Specifically, optical fiber sensors which measure field amplitude, phase, polarization, modal properties, wavelength and frequency are possible [1].

Optical fiber sensors have been demonstrated for the qualitative measurement of ultrasonic fields for more than ten years, although more conventional methods, typically employing piezoelectric transducer elements, have been used for many decades. The quantitative measurement of ultrasonic waves and its relation to material analysis has been considered in detail by many authors. Of these, Breckenridge and co-workers at NIST [2], and Green and co-workers at Johns Hopkins [3], have analyzed the performance of both contacting piezoelectric transducer methods and non-contacting interferometric optical methods to determine the combination of in-plane and out-of-plane particle motions which occur at a surface due to localized wave-generating events. Information obtained from such measurements may be used to determine the location of impacts on the surface of a material, or the occurrence and potential nature of internal acoustic emission events generated by the initiation and propagation of cracks, delamination or other internal sources related to the local rearrangement of physical microstructure.

This workshop paper briefly discusses wave propagation associated with localized generation events, describes experimental methods implemented to measure surface wave components, and reports experimental results.

2. ULTRASONIC IMPULSE WAVE GENERATION AND PROPAGATION

The propagation of ultrasonic waves from both an idealized step function surface source and buried particle displacement sources is considered in detail for large, isotropic, homogeneous materials by Knopoff and Pekeris [4]. Both treatments assume simple Green's function models for the propagation sources, and carry out the analyses to predict surface and internal particle motion fields in time and space. The results of these works indicate that for both surface and buried sources, oscillatory longitudinal and shear displacement components are in general created internally. Where the material supporting wave motion is bounded by a surface, bulk wave to surface wave conversion occurs and the particle motion fields at the surface may be written in terms of in-plane and out-of-plane displacements versus time.

Locally, the particle displacements associated with such surface acoustic wave fields are elliptical retrograde with respect to the propagation direction. Surface wave motion decays with distance measured away from the surface and into the material, and the orientation of the ellipse changes at a distance on the order of one acoustic wavelength below the surface. An exaggerated view of this type of motion is shown in Figure 1.

3. OPTICAL FIBER EFFI SENSOR RESPONSE TO ULTRASONIC WAVES

Both extrinsic and intrinsic optical fiber sensor methods have been used to measure surface wave displacement components. Extrinsic techniques which use the fibers simply to transmit coherent light to and from the insonified surface allow the implementation of conventional optical interrogation geometries. Intrinsic techniques instead have employed the high frequency surface acoustic wave (SAW)-induced strain modulation in the fiber to modulate the optical phase and polarization properties of the propagating light.

The EFFI response to propagating SAW is straightforward. A representative diagram of the EFFI sensor element is shown in Figure 2. Here, coherent light from an input single mode fiber is partially reflected from its cleaved end held inside a hollow core fiber used as a splice tube. Light transmitted from this end of the fiber is partially reflected by the opposing end surface of the multimode fiber. Both of the reflected signals interfere to produce an output signal which may be analyzed to determine relative surface motion and thus local strain [5].

The in-plane components of SAW on the surface supporting the EFFI sensor head differentially modulate the relative positions of the two fiber endfaces, and produce an output signal which may be analyzed to quantitatively determine the in-plane displacement of the SAW. Further, by knowing the properties of the material supporting the wave, the normal component may be derived directly, thus yielding complete SAW displacement field information.

Additionally, by controlling the relative separation of the endfaces of the opposing fibers and the locations of their attachment to the material surface, the bandwidth of the EFFI sensor element to propagating SAW may be controlled. For an endface distance of exactly one-half an acoustic wavelength, for example, the sensitivity of the element is maximized. A 3dB bandwidth of approximately two octaves is possible [6].

4. EXPERIMENTAL RESULTS

SAW generated by breaking pencil lead on a large aluminum substrate to simulate acoustic emission pulses were detected using an EFFI sensor element and associated source and detector optics and electronics. Typical results for the experimental geometry shown in Figure 3 are given in Figure 4

with experimental results obtained by Sachse using a similar experimental arrangement but piezoelectric transducers [7]. The two signals look very similar, indicating an approximate verification of the model of calibrated EFFI response to ultrasonic waves.

5. CONCLUSION

EFFI sensors have demonstrated for the calibrated detection of ultrasonic waves in materials. The bandwidth of the sensor is controlled by the separation of the two fibers in the EFFI sensor head. Applications in the analysis of materials and structures are suggested.

6. REFERENCES

1. Optical Fiber Sensors, E. Udd, ed., Academic Press, 1991.
2. F. Breckenridge, C. E. Tschiegg and M. Greenspan, J. Acoust. Soc. Am. 57(3), March 1975, pp. 636-642.
3. R. A. Kline, R. E. Green and C. H. Palmer, J. Acoust. Soc. Am. 64(6), Dec. 1978, pp. 1633-1639.
4. C. L. Pekeris, Proc. N. A. S., 41, 1955, pp. 469-480.
5. K. A. Murphy, M. F. Gunther, A. M. Vengsarkar and R. O. Claus, Opt. Lett. 16(4), Feb. 1991, pp. 273-275.
6. C. H. Palmer, R. O. Claus and S. E. Fick, Appl. Opt. 16, 1976, pp. 1849-1856.
7. W. Sachse, personal communication.

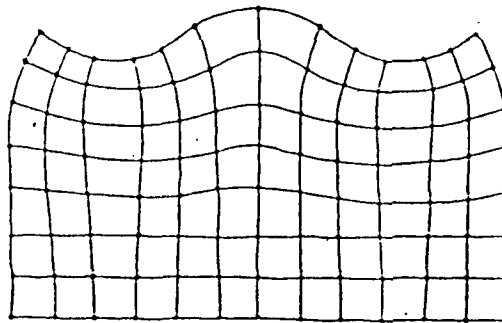


Figure 1. Exaggerated diagram of SAW particle motions.

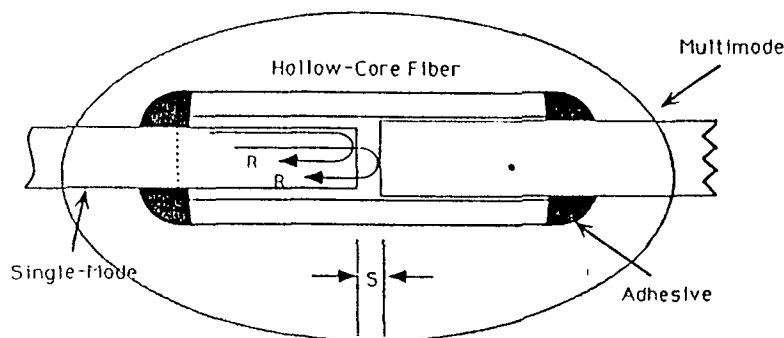


Figure 2. EFFI sensor head geometry for the detection of ultrasonic surface waves. Differential motion between the two opposing fiber endfaces allows quantitative measurement of SAW amplitude.

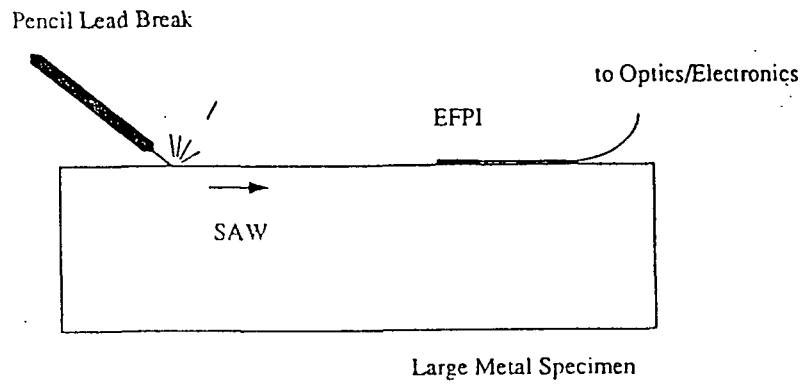


Figure 3. Experimental geometry for breaking of pencil lead on specimen to which EFFI fiber sensor is attached.

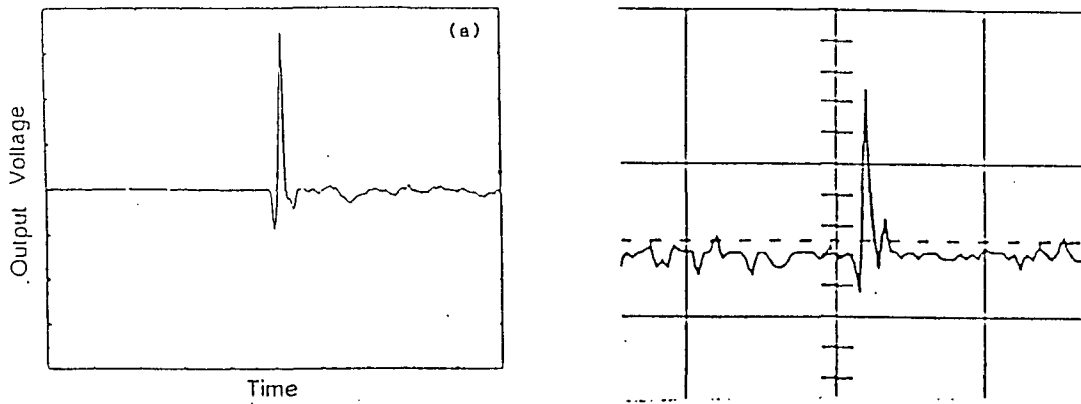


Figure 4. Piezoelectric sensor data (left) [7], and fiber EFFI sensor data (right) for pencil lead-generated simulated AE events.